Diving Physiology

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Objectives

1. Understand gas laws important to diving; be able to calculate pressure as a function of depth
2. Understand limitations/complications of diving and the relevant gas laws
3. Understand the cause, symptoms, and treatment of

Boyle's Law

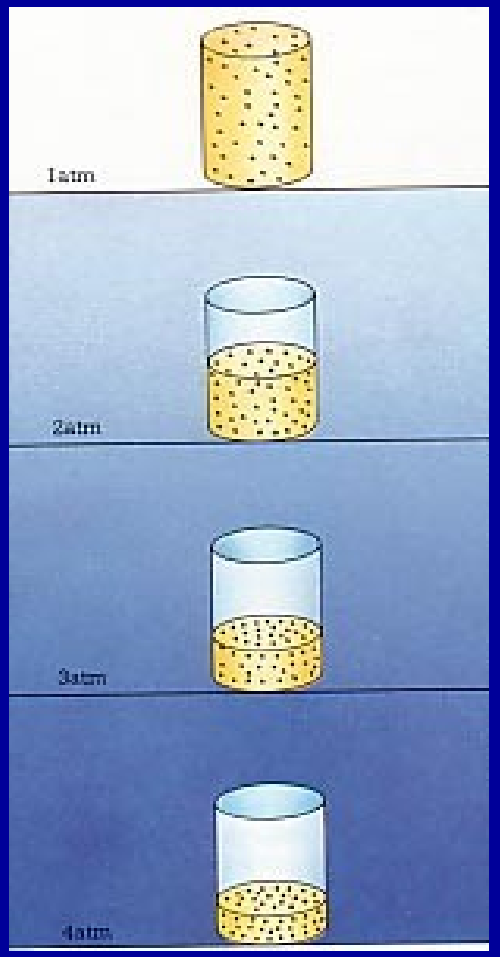
- "for any gas at a constant temperature, the volume of the gas will vary inversely with the pressure"
  - $P_1V_1 = P_2V_2$ (pressure is absolute!)
  - greatest pressure change is near the surface!

Absolute Pressure (ATA)

$$ATA = \frac{\text{Depth} + 33\ \text{FSW}}{33}$$

fsw=feet seawater

Boyle's Law



Boyle's Law

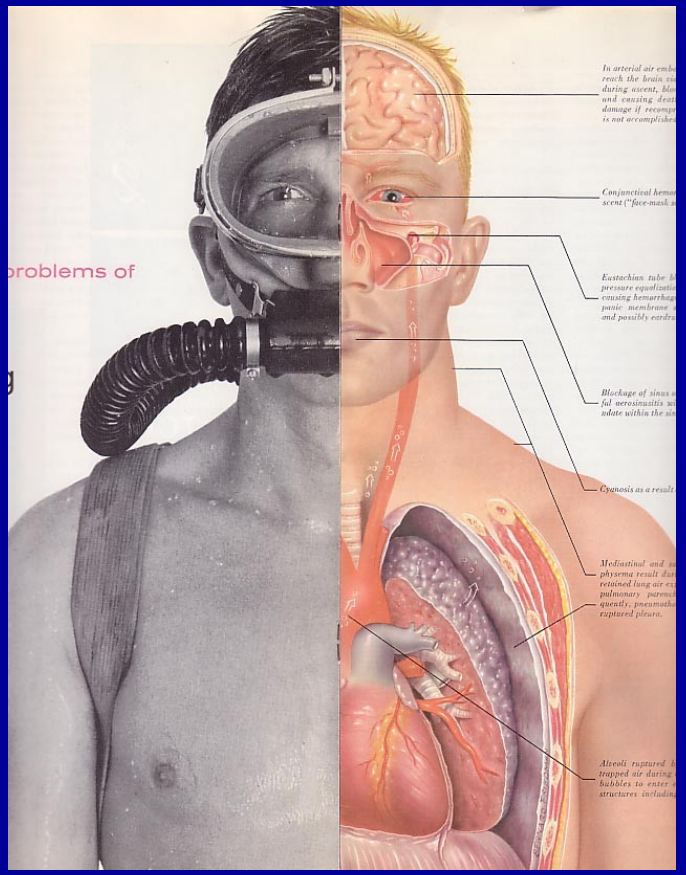
- Relationship to diving:
- Immersion effects
- Squeezes
- Pulmonary overinflation syndromes (POIS)

Immersion Effects

- Blood squeezed to thorax (1-1.5 Liter)
- Increased Blood Pressure (BP), Stroke Volume(SV), Cardiac Output(CO)
- Results in Atrial Natriuretic Peptide(ANP) and Diuresis
- Mild decrease in Functional Residual Capacity (FRC) and Vital Capacity (VC)
- Need pressurized air supply—lung can’t draw air via snorkel at depth > 3 feet

Barotrauma or “Squeeze”

- **ESSENTIAL INGREDIENTS:**
  - **GAS FILLED SPACE.**
  - **RIGID WALLS.**
  - **AMBIENT PRESSURE CHANGE .**
  - **VASCULAR PENETRATION.**
  - **ENCLOSED SPACE.**

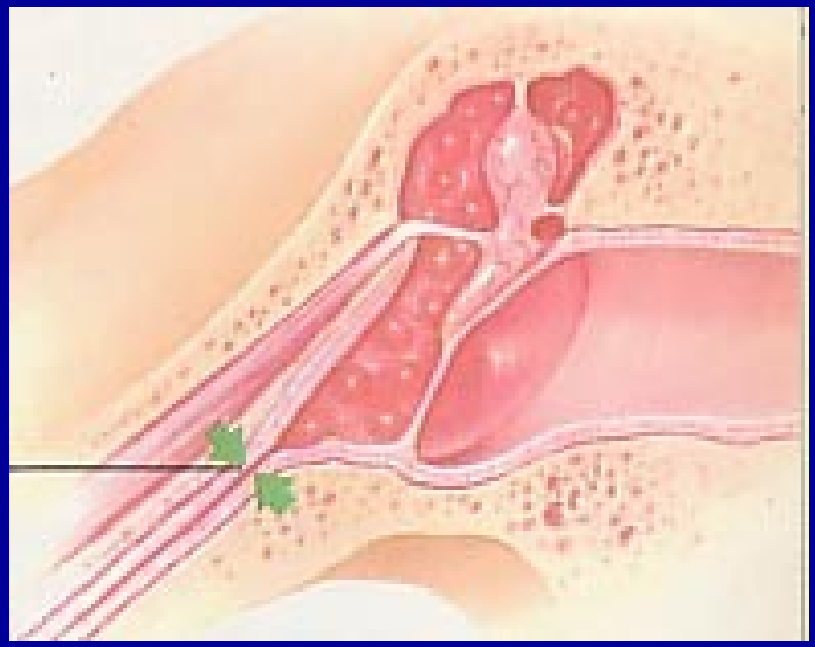


Squeezes

1. Mask—from forgetting to use nose
2. Suit—from poorly fit suit
3. Sinus—from polyps, infection, congestion
4. Tooth—from cavities, or bad dentist
5. Ear –middle ear squeeze is #1 dive injury
6. Lung—RARE on breathhold

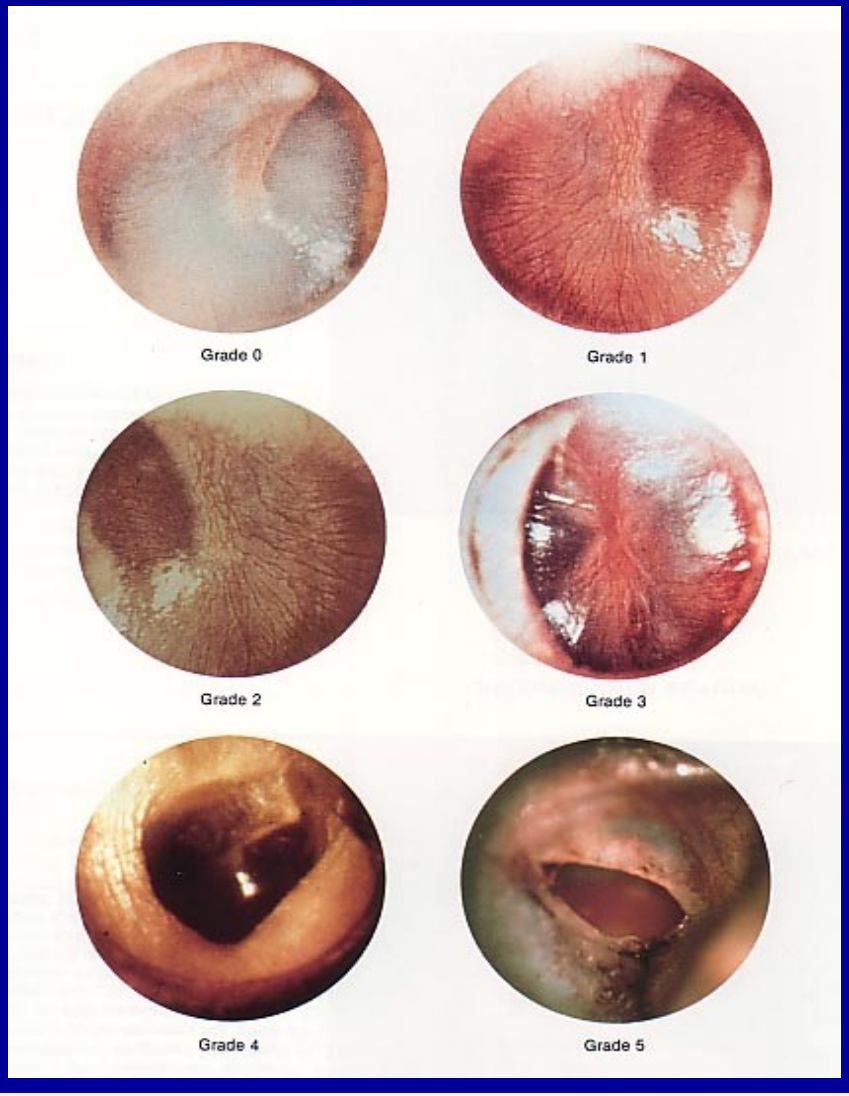
Middle Ear "Squeeze" (Aerotitis)

- Most come medical complaint in divers
- Cause by poor technique, poor anatomy, congestion
- Eustacian Tube blocked if pressure differential 60 mmHg, locked at 90 mmHg (2.6-3.9 feet below surface)



Middle Ear “Squeeze”

- Symptoms, no signs
- TM injection
- Slight TM hemorrhage
- Gross TM hemorrhage
- Blood filled middle ear with bulging TM
- TM rupture

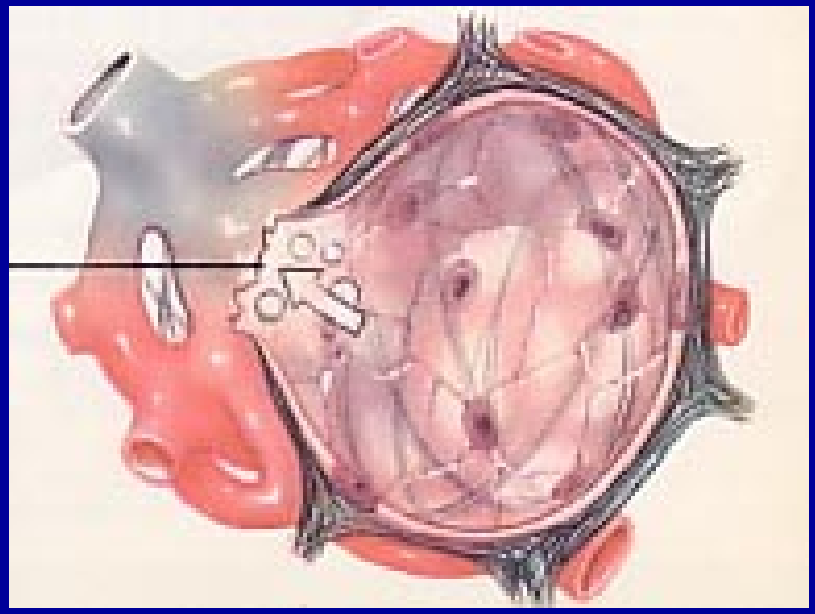


Reverse Squeeze

1. Gas under pressure enters air filled space at depth
2. This Gas unable to escape during ascent—expands and ruptures
3. Ear, Sinus, Tooth, Lung
4. LUNG—POPS: Pulmonary Over-Pressurization Syndrome (POIS)

Pulmonary Over-Inflation Syndrome

- Aveolar rupture requires about 70 mmHg pressure gradient
- May occur in water as shallow as one meter
- mediastinal or subcutaneous emphysema, Pneumothorax, or
- Arterial Gas Embolism (AGE)



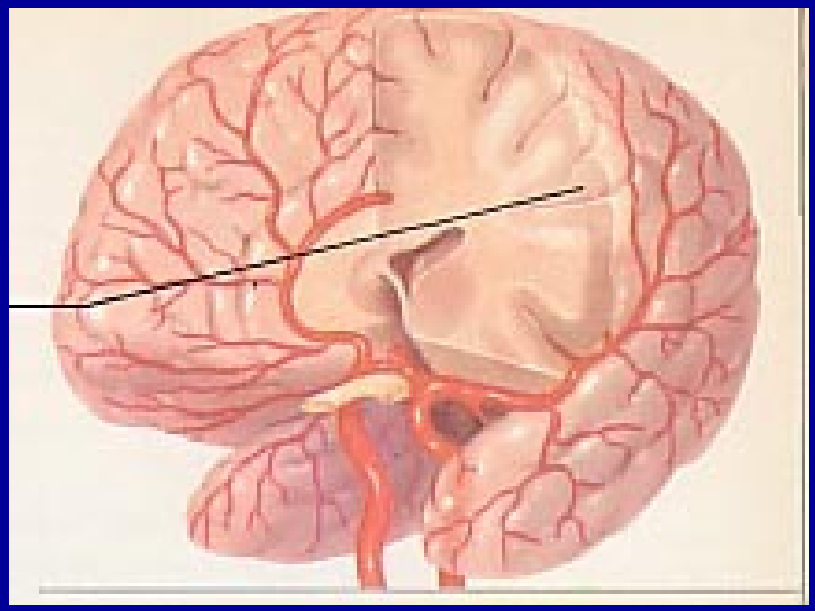
AGE

–***<u>Arterial Gas Embolism</u>***: Alveolar rupture with air bubbles entering the capillaries of the lungs and traveling to the heart and then distributed throughout the body, usually the brain (CNS) but can be the heart.

- ***This is the most serious potential complication of diving caused by excess air pressure in***

Cerebral Artery Gas Embolism

- Always symptomatic within 10 minutes of surfacing
- Confusion, ataxia, sensory symptoms, loss of consciousness
- Immediate recompression is indicated!!!



AGE

The working rule is: Any diver who has obtained a breath of compressed gas from any source at depth who surfaces and remains unconscious or looses consciousness or has any neurological deficit within 10 minutes of reaching the surface, must be assumed to be suffering from A.G.E.

Dalton's Law of Partial Pressures

- **Dalton's Law: "the total pressure exerted by a mixture of gases is equal to the sum of the pressures of each individual gas "**
- **application- gas toxicity**
- **p = ATA X Gas %**

Partial Pressure Calculations

"What is the pO2 of air at 60FSW?"

- **partial pressure = (ATA) (% gas)**
- **ATA = (60 fsw + 33 fsw)/33 fsw = 2.8 ATA**
- **% gas = 0.21**
- **pO2 = (2.8 ATA)(0.21) =** 0.59 ATA

Dalton's Law

- Relationship to diving
  - Gas toxicity at depth
    - Nitrogen narcosis
    - O2 toxicity
  - Decompression tables
    - Partial Press of gases determines the decompression tables along with Henry's law

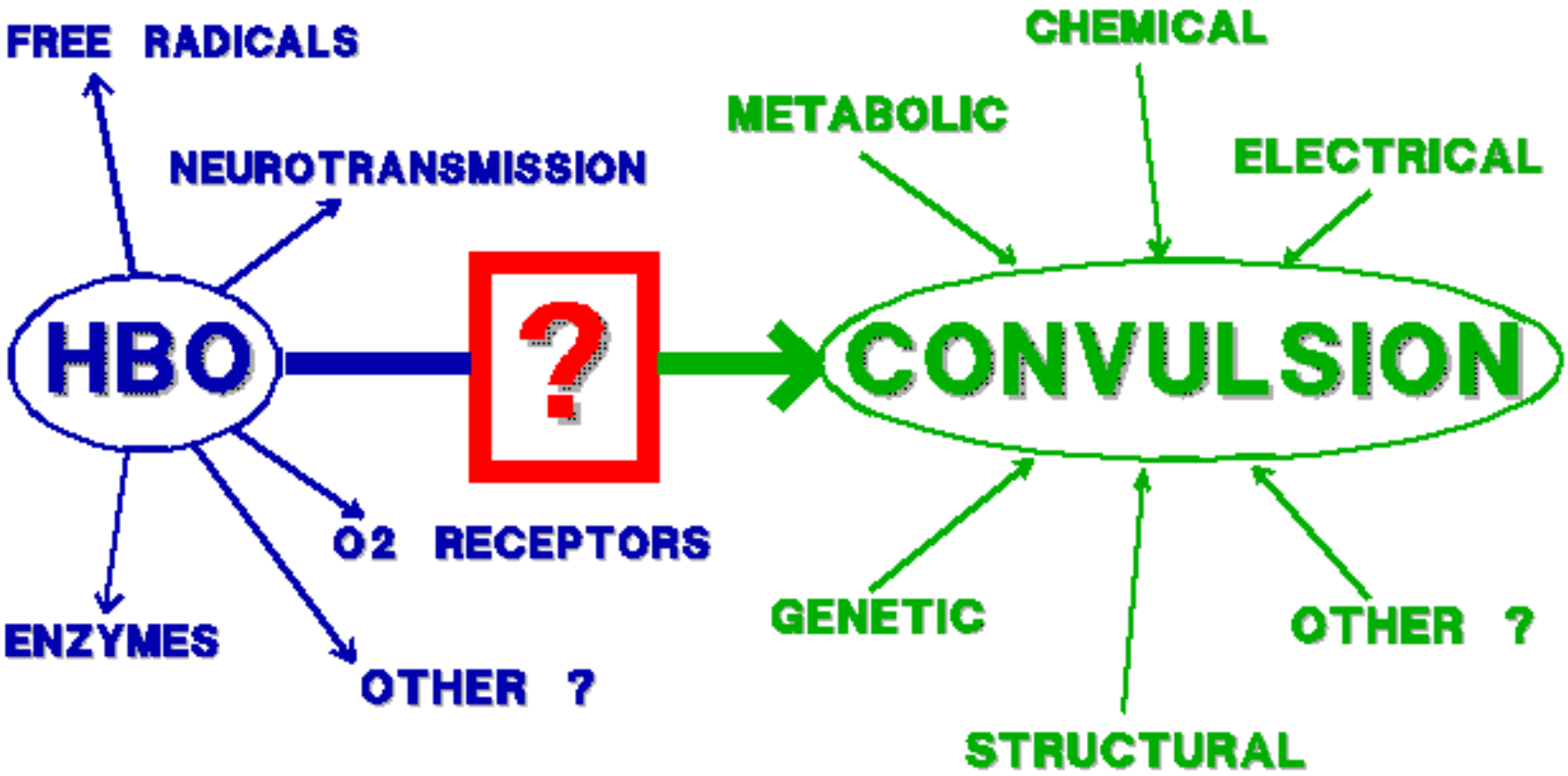
Nitrogen Narcosis

- **“Rapture of the Deep”**
- **Deeper than 100 FSW, every additional 50 FSW produces a narcotic effect equal to one martini**
- **USN does not dive air below 180**

CNS Oxygen Toxicity

- **Results from breath oxygen at partial pressures greater than 1.6 ATA (218’ on air or 20’ if 100%)**
- **Symptoms = VENTID-C (Vision :“tunnel”, Ears: “ringing”, Nausea, Twitching, Irritability, Dizziness, Convulsions)**
- **May not have VENTID before Seizure (C)**
- **Seizure is fatal---leads to drowning**

WHAT MECHANISM LINKS HBO EXPOSURE AND CONVULSION ?



HBO=hyperbaric oxygen

Recent Research:

- **During HBO exposure both Cerebral Blood Flow (CBF) and Mean Arterial Press (MAP) reliably increase before seizure onset.**
- **CBF and MAP are potential biomarkers of HBO brain toxicity.**
- **CBF and MAP could be used as**

Pulmonary Oxygen Toxicity

- Results from extended breathing of oxygen at partial pressures greater than 0.55 ATA (53 ft for air)
- Only underwater research habitat is at 50’
- Symptoms = chest tightness, cough, chest pain, shortness of breath, decreased Forced Vital Capacity

Pulmonary Oxygen Toxicity

- Free Radical formation – key to pulmonary oxygen toxicity
- Three species of concern
  - Superoxide (O_2^-)
  - Hydroxyl ion ($-OH^-$)
  - Hydrogen peroxide (H_2O_2)
- Anti-oxidant Therapy/Prophylaxis
- Air Breaks are used to prevent during HBOT

Henry's Law

- Solubility of a gas in a liquid is directly proportional to the pressure of the gas over the solution.
- $Conc_{gas} = Press_{gas} \times Sol_{gas}$
- Solubility coeff varies depending on the solvent
- Daily Example: Open a soda can

Henry's Law

- Main solvent in humans is water
- As a diver descends deeper, more gas will dissolve in the body tissues and on ascent the dissolved gas must be released.
- Relationship to diving: Decompression Sickness (DCS)

Decompression Sickness

- **Clinical signs or symptoms produced by the formation of bubbles in the tissues of the body resulting from supersaturation of the body with an inert gas**
- **For most diving this is NITROGEN**

Decompression Sickness

- Military Relevance
- Requirement for surface recompression
- Time requirement to off-gas inert gas: safety and mission length compromised

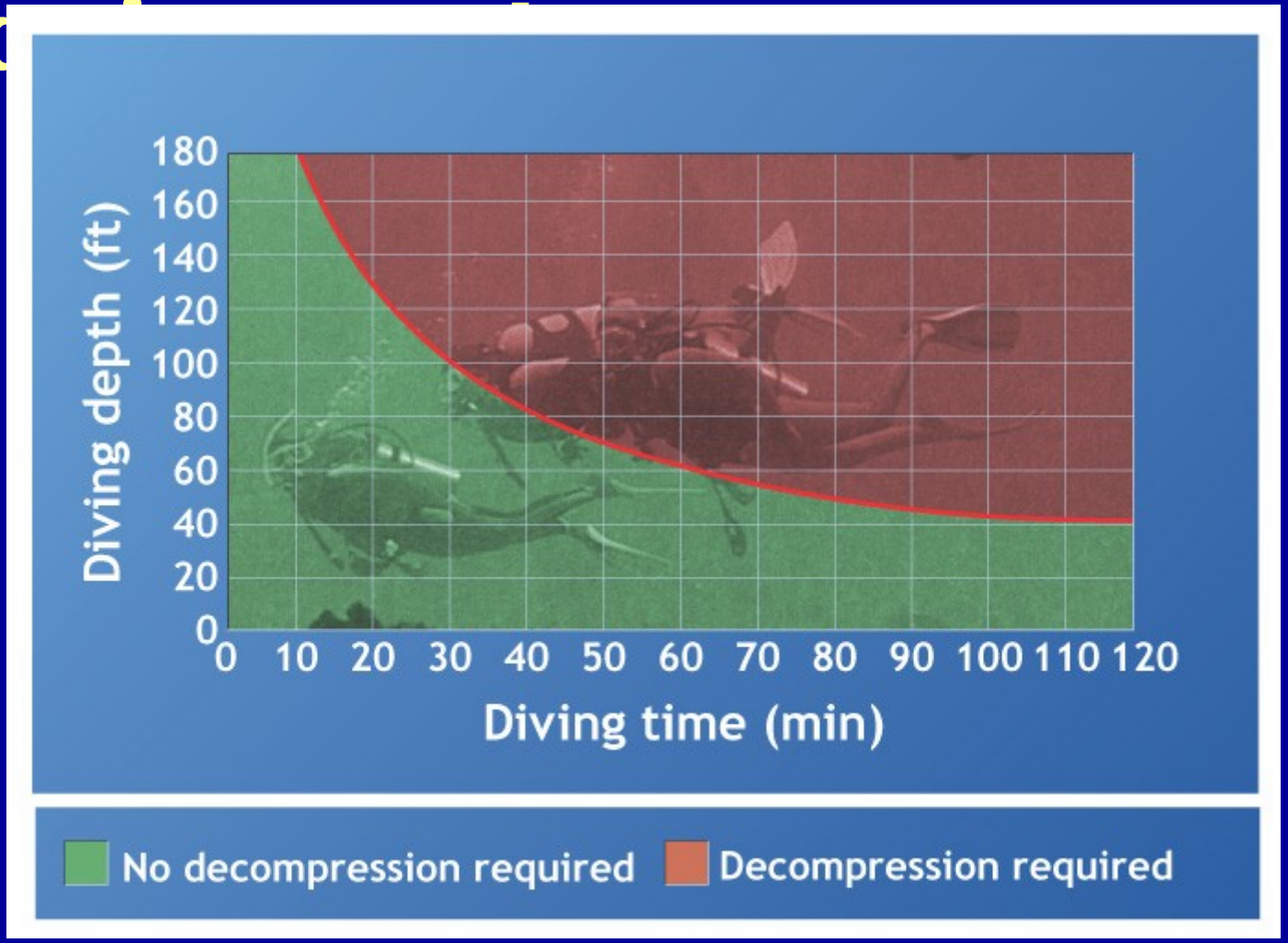
Some Related Topics :

- Novel Non-Recompressive Therapies
  - Biochemical Decompression
  - Perfluorocarbon
- Temperature effects
- Immune modulation and

Perfluorocarbons: increasing inert gas solubility in blood

- **Synthetic oils used as blood substitutes or for liquid breathing.**
- **High solubility for all gases (O_2, N_2, He).**
- **Intravenous injections increase inert gas loss from tissues and decrease circulating bubbles: increases off-gassing.**

Decompression Requirements



Bubble Effects

- **Mechanical**
  - **obstruction of blood flow**
  - **tissue distortion**
- **Non-mechanical**
  - **activation of coagulation cascade**
  - **leukocyte activation**
  - **complement-mediated injury**

DCS Onset Timeline

- **50% < 30 minutes after surfacing**
- **85% < 1 hour after surfacing**
- **95% < 3 hours after surfacing**
- **1% > delayed more than 6 hours**

DCS Type I

- Limb pain only - outside the tank top, bathing trunk distribution
- Upper extremities - standard divers
- Lower extremities - sat divers & caisson workers
- Lymphatic manifestations - obstruction of the lymphatics by bubbles

DCS Type I

- **Cutaneous manifestations - Pruritis**
- **Cutis Marmorata (marbling) - venous obstruction of the skin or vascular spasm in response to tissue bubbles**

  Often a harbinger of more serious forms of Decompression sickness!!!

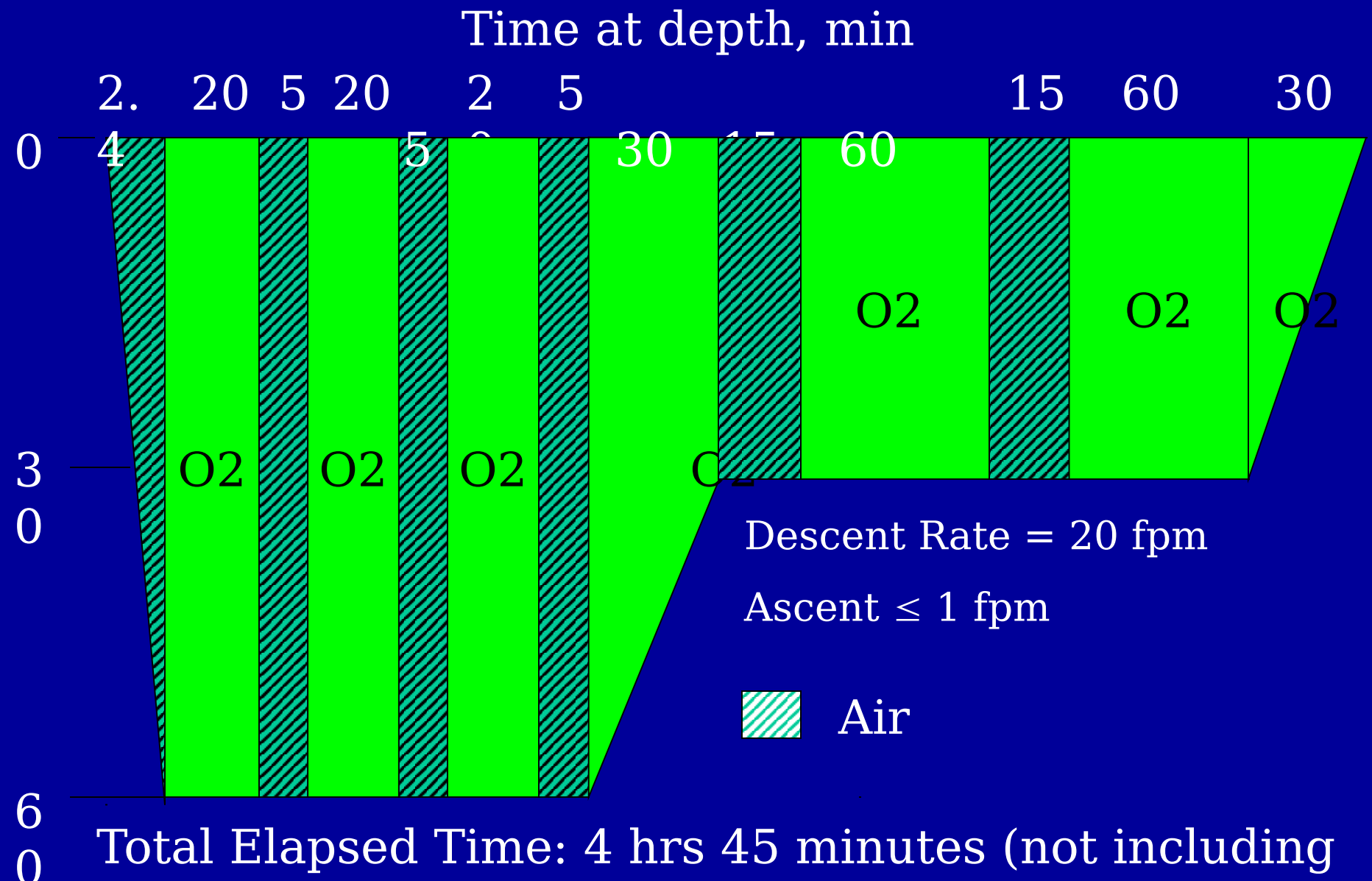
DCS Type II

- **Pulmonary DCS - “chokes”: substernal pain, cough, dyspnea**
- **Neurologic DCS – “staggers” brain, spinal cord: Cephalgia with CN deficits, hemiparesis, paraplegia, urinary & fecal incontinence, ataxia, extreme fatigue, shock**

DCS Treatment=Recompression with HBO

- Purpose of therapy
  - –Decrease bubble size
  - –Promote off-gassing
  - –Increase oxygen delivery to injured tissues

Treatment Table 6



Total Elapsed Time: 4 hrs 45 minutes (not including descent time)

Factors Potentially Affecting the Risk of DCS

- Age
- Gender
- Hydration status
- Body fat
- Cardiovascular fitness
- Recent alcohol consumption
- Previous injury
- Exercise
- Adaptation to decompression stress
- Dive profile
- Water temperature
- Inert gas

Thermoregulation: Cold Exposure

- Thermoneutral water temp is 91 F
- Water temp of 80 = 42 in air
- High conductive/convective heat loss
- Respiratory heat loss critical at depth
  - Causes Core temp drop
  - Bronchorrhoea – cold gas stimulated secretions
  - Beyond 330 ft HeOx gas is

Thermal Control: Cold Exposure

- **Prevention**
- **Hydration (diuresis, alc, caffeine, work)**
- **Protective clothing**
- 55-65 F (wet suit)
- 40-55 F (dry suit)
- <40 F (hot water suit)
- Acclimation to cold is BAD
  - Less shiver response
  - Less vasoconstriction

Thermoregulation: Heat Exposure

- Vasodilation
  - Dehydration – circulatory compromise – collapse
- Acclimatization
  - Renal, CV, pulmonary, endocrine
    - Adrenal Aldosterone increases
      - Decreasing perspired sodium

Thermal Control: Heat Exposure

- Protection
  - Ice-vests
  - monitoring
- Prevention
  - Hydration and acclimatization

Light

- Color and depth
  - RED
  - ORANGE
  - YELLOW
  - GREEN
  - BLUE, INDIGO, VIOLET

- Hence the term “deep blue”

Light

Refraction

–Objects underwater appear closer and larger

- Effects hand-eye coordination

–Dispersion of light with turbidity—similar to fog—brain interprets as farther away

–Color effected by salinity/turbidity/particulates

Sound

–Sound travels farther and faster underwater because it is more dense than air (travels 4 times faster)

–The colder the water is, the more dense it is.

–Sound travel is effected by thermo clines

NAVY Fitness to Dive

- Governed by MANMED 15-66 and BUMED note 6120
- Remember Medications (INH)
- Middle/Inner Ear Surgery
- ETD
- Severe Motion

Fitness to Dive

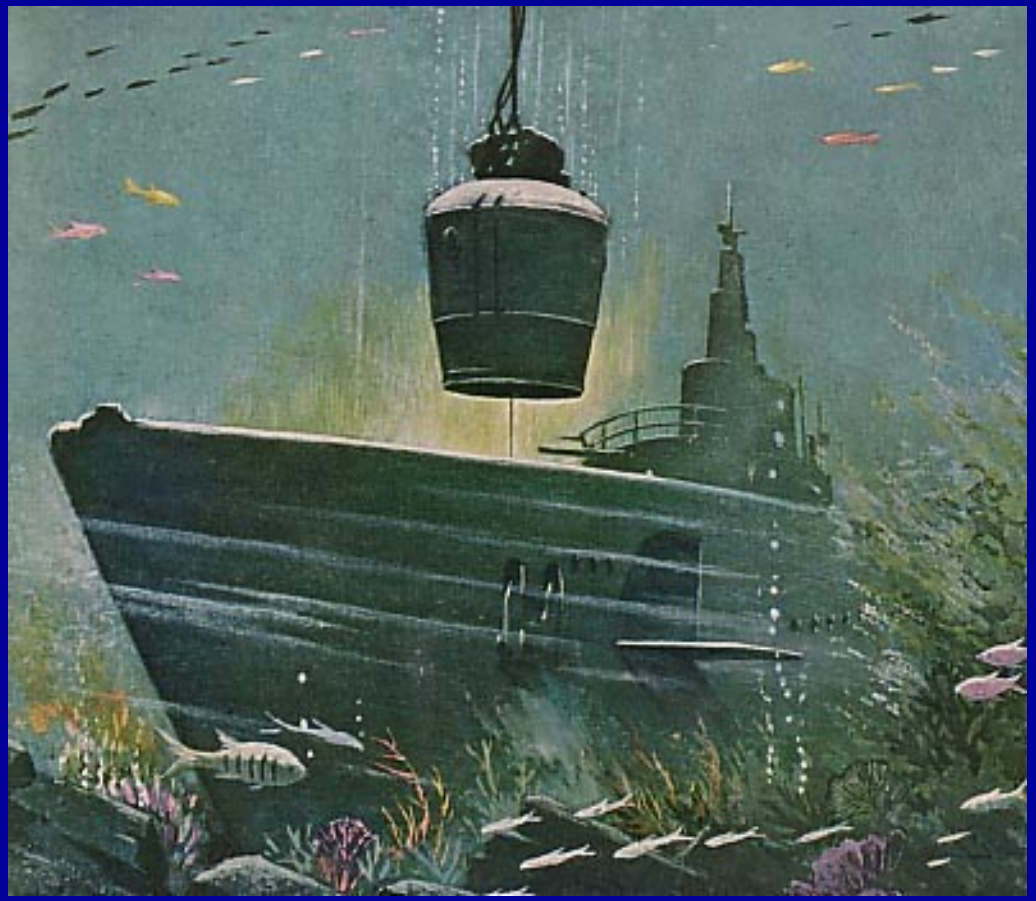
- Pulmonary issues
  - Compromise of pulm function w/ exercise
    - COPD
    - Asthma after age 12 ABS DQ
- Spontaneous pneumothorax
- Recurrent Pulm.

Fitness to Dive

- Cardiovascular issues
  - History of angina/infarct ABS DQ
- Neurologic issues
  - Seizure history is ABS DQ
  - Severe CHI
- Absolute, Relative, and Temporary disqualifications

Submarine Rescue Chamber

- USS Squalus
- First use of an SRC
- Invented by Charles Momsen



Temperature and DCS

- Divers
- Combat swimmers
- Submariners

Deep Submergence Rescue Vehicle

- 2000 FSW rescue capability
- 24 survivors per trip